Theoretical ν_τ Charged-Current Interaction Cross Section

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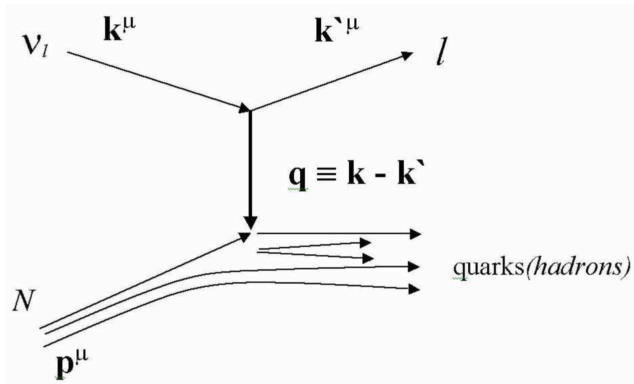
Introduction

- First must establish deep inelastic scattering region - if $W > 2$ and $Q > 2$, then interaction occurs in DIS region
  - Calculate W and Q
  - requires neutrino energy estimate
  - requires tau energy estimate
- Once established, must calculate theoretical cross section
  - Normally neglect mass of lepton
  - Cannot do this with tau

Calculating W and Q



$$W = (P + q)^2 = P^2 + q^2 - 2P \cdot q = \qquad (1)$$

$$M_N^2 + q^2 - 2M_N(E_{\nu_\tau} - E_\tau) \qquad (2)$$

where P is the four-momentum of the nucleon, M_N is the mass of the nucleon, E is the energy of the neutrino, E' is the energy of the tau, and q^2 is:

$$q^2 = -Q^2 = (k - k')^2 = m_\tau^2 - E_{\nu_\tau}(E_\tau - p_\tau \cos\theta)$$

where k is the four-momentum of the neutrino and k' is the four-momentum of the tau.

Estimating the Tau Neutrino Energy

Using momentum conservation:

$$p_\nu = p_\tau \cos\theta + p_W \cos\beta \qquad (3)$$

where β is the angle between the W boson and the neutrino direction and θ is the standard angle between tau and neutrino. β is calculated using the vector sum of all track except the lepton. We also have:

$$0 = p_\tau \sin\theta - p_W \sin\beta \qquad (4)$$

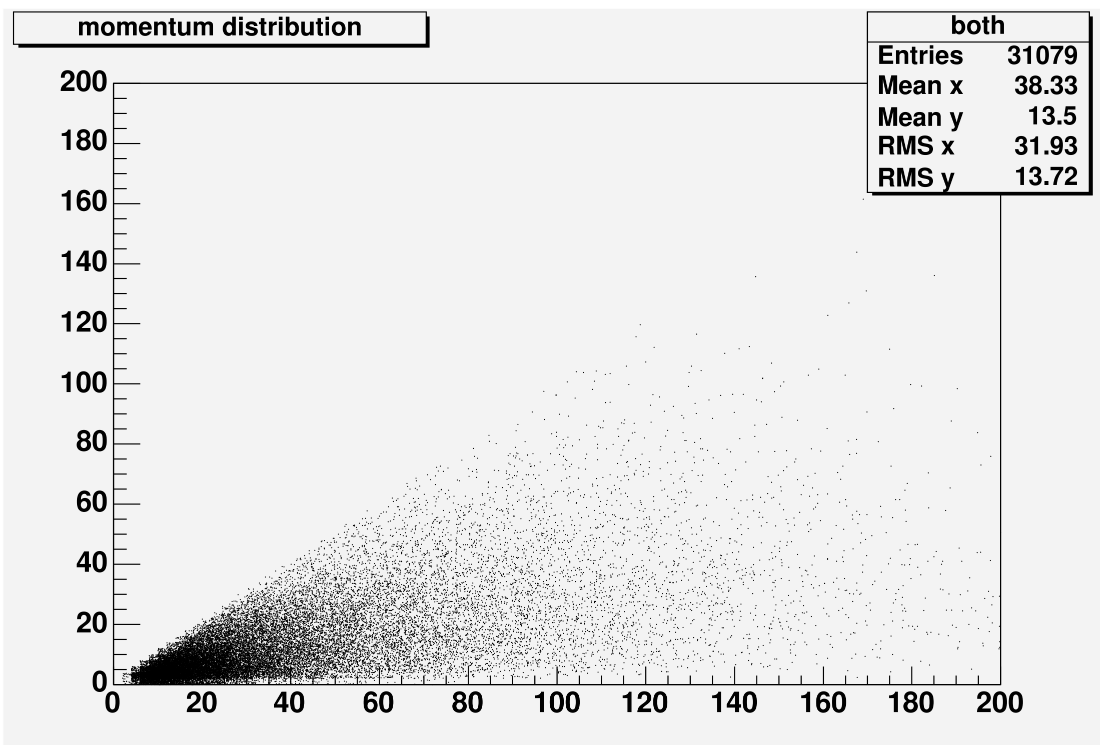
Combining these:

$$p_\nu = p_\tau \cos\theta + \frac{p_\tau \sin\theta}{\sin\beta} \cos\beta = p_\tau \left(\cos\theta + \frac{\sin\theta}{\tan\beta} \right) = E_\nu \qquad (5)$$

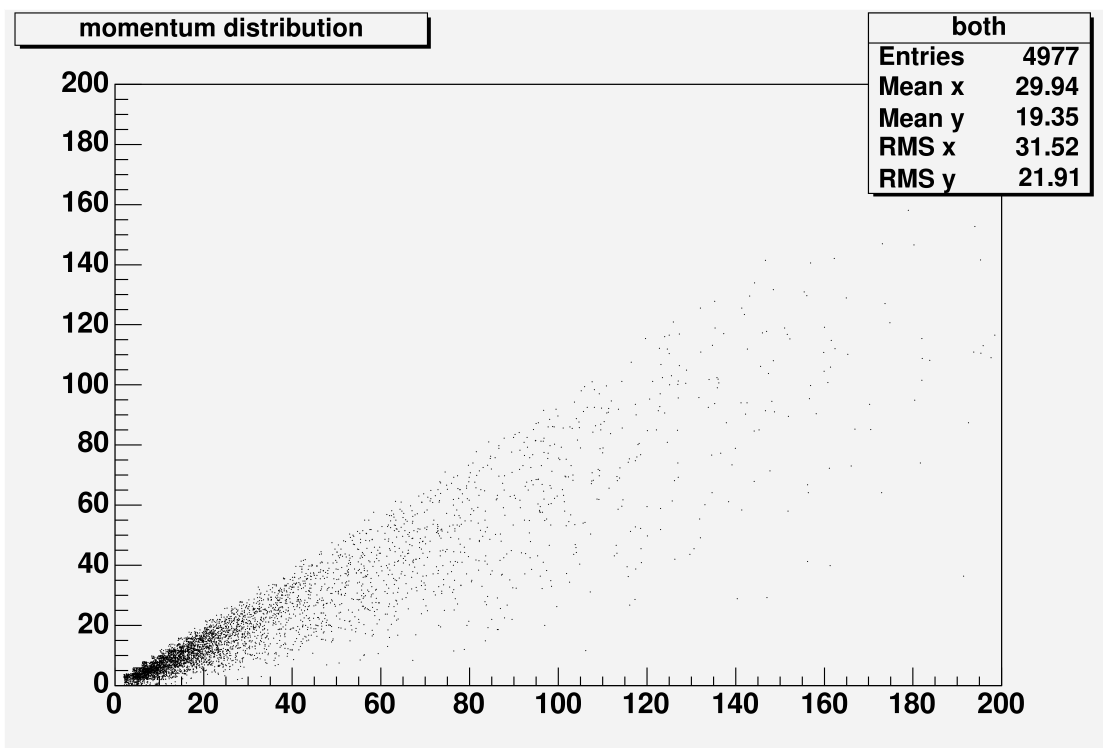
Estimating the Tau Energy

A minimum for the tau energy is the energy of the tau daughter(s). I plotted the energy of the tau vs. the energy of the tau's daughter(s) for the kink and trident cases.

This is the distribution of momentum of the daughter (y-axis) vs. momentum of the tau (x-axis) for the kink event:



This is the distribution of momentum of the daughter (y-axis) vs. momentum of the tau (x-axis) for the trident event:



Trident Events

Event	p1	p2	p3
3334_19920	$7.8^{+3.6}_{-2.0}$	$18.9^{+20.7}_{-6.8}$	$3.3^{+1.2}_{-0.7}$
3296_18816	$2.3^{+1.3}_{-0.6}$	$0.9^{+1.0}_{-0.3}$	$1.3^{+2.1}_{-0.5}$

Event	θ (mrad)	α (mrad)	ptot
3334_19920	40	100	$30.0^{+21.0}_{-7.1}$
3296_18816	141	272	$4.5^{+2.7}_{-0.8}$

Trident Results

Event	E_ν (GeV)	E_τ	q^2 (GeV^2)
3334_19920	$38.9^{+27.2}_{-9.2}$	$30.1^{+21.0}_{-7.1}$	$-6.4^{+5.7}_{-1.9}$
3296_18816	$6.8^{+4.1}_{-1.2}$	$4.9^{+2.9}_{-0.8}$	$-5.5^{+2.6}_{-0.8}$

Event	W^2 (GeV^2)	Q	W
3334_19920	$23.2^{+24.4}_{-8.1}$	$2.5^{+1.1}_{-0.8}$	$4.8^{+1.1}_{-0.4}$
3296_18816	$9.3^{+5.9}_{-1.8}$	$3.0^{+1.0}_{-0.3}$	$2.2^{+0.6}_{-0.2}$

These values for W and Q are in the deep inelastic scattering region.

Kink Events

Event	θ (mrad)	α (mrad)	p_d (GeV)
3024_30175	28	276	$4.6^{+1.6}_{-0.9}$
3039_01910	67	30	$2.9^{+1.5}_{-0.8}$
3333_17665	16	208	$21.4^{+14.4}_{-6.4}$

Kink Results

Event	E_ν (GeV)	E_τ	q^2 (GeV^2)
3024_30175	$5.1^{+1.8}_{-1.0}$	$4.9^{+1.5}_{-1.0}$	$-3.2^{+1.5}_{-0.9}$
3039_01910	$9.4^{+4.9}_{-2.6}$	$3.4^{+1.8}_{-0.9}$	$-1.5^{+0.7}_{-0.4}$
3333_17765	$23.1^{+15.5}_{-6.9}$	$21.5^{+14.5}_{-6.5}$	$-3.1^{+2.1}_{-0.9}$

Event	W^2 (GeV^2)	Q	W
3024_30175	$3.8^{+2.5}_{-1.5}$	$1.8^{+0.5}_{-0.3}$	$2.0^{+0.6}_{-0.4}$
3039_01910	$9.3^{+4.8}_{-2.6}$	$3.5^{+0.2}_{-0.1}$	$12.5^{+0.8}_{-0.4}$
3333_17765	$1.1^{+0.7}_{-0.3}$	$1.8^{+0.6}_{-0.3}$	$1.1^{+0.4}_{-0.2}$

I think this approximation will be fine, especially because I used the minimum tau energy in this calculation.

Calculating the Cross Section

Currently I have an expression which involves integrals over the parton distribution functions, $q(x)$ and $\overline{q}(x)$. I am trying to estimate these. I have included the expression below. I will say more about how I arrived at this expression when I have a number.

$$\begin{aligned}\sigma^{\nu N} = \frac{2G^2ME}{\pi}\Bigg\{&\left(1-\frac{m_\tau^2}{4E^2}\right)\int_0^1 xq(x)dx \\ &- \frac{M}{4E}\int_0^1 x^2q(x)dx + \frac{m_\tau^2}{2ME}\int_0^1 q(x)dx \\ &+ \left(\frac{1}{3}-\frac{m_\tau^2}{4E^2}\right)\int_0^1 x\overline{q}(x)dx - \frac{M}{4E}\int_0^1 x^2\overline{q}(x)dx \\ &+ \frac{m_\tau^2}{4ME}\int_0^1 q(x)dx\Bigg\}\end{aligned} \tag{6}$$